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Collaborative problem-based learning in mathematics: A cognitive load perspective

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Abstract

Mathematics educators have struggled to improve learners' performance in mathematics. Based on the cognitive load theory, many conventional instructional formats are less than effective because little consideration is given to the concept of cognitive processing capacity. Thus, investigation into problem-based learning (PBL) has been undertaken. This study examined the effects of PBL on educational statistics course. Six PBL modules, which consisted of scenarios and guided questions, were used during a 10-week teaching. Comparing students' performances based on two tests showed that there was a significant difference between the mean performance of the PBL group and that of the conventional group – indicating PBL efficacy.

Keywords: Problem-based learning; guided questions; statistic learning performance; mental load

1. Introduction

For many decades, the mathematical community has struggled to indicate the role of mathematics, science and technology in life. Consequently, there have been numerous changes made to the mathematics curriculum used in schools and institutions of higher learning. In particular, students should be able to develop more complex, abstract, and powerful mathematical structures to enable them to solve a broad variety of meaningful real-life problems. Furthermore, students ought to become autonomous and self-motivated in their mathematical activities such as acquiring mathematical concepts, skills and problem solving; meta-cognitively aware of their mathematical thinking; highly motivated in mathematics learning and develop positive attitudes towards mathematical task.

In the last 20 years, many studies were conducted in implementing problem-based learning (PBL) in professional education and training (Albanese & Mitchell, 1993; Savin-Baden, 2000; McPhee, 2002; Gibson 2002; Pedersen & Liu, 2002). Based on Vernon and Blake (1993), meta-analysis of medical students in PBL curricula found that they performed slightly worse on tests of basic science knowledge but performed better on tests of clinical knowledge compared to that of traditional medical students. Dochy, Segers, Van den Bassche and Struyven, (2005) mentioned that there is no effect of PBL on students' declarative knowledge, however in some studies which compared PBL

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students with traditional students on measure of knowledge application indicated a moderate effect size favouring PBL students. According to Patel, Groen and Norman's (1993), study on students from different universities with different characteristics showed that the PBL group was more likely to make errors rather than students with traditional approach; however the students of PBL group created more elaborated explanation compared to the sparse explanation of students in the traditional approach. The results of the study by Patel et al. (1993) indicated that PBL approach impedes the development of reasoning strategies. In addition, a study which conducted by Hmelo, Guzdial, and Turms (1998) on first year medical students indicated that PBL students generated more accurate and coherent problem solving compared to traditional medical students.

Another work that supported the positive effects of PBL was a study conducted by Derry, Hmelo-Silver, Nagarajan, Chernobilsky, and Beizel (2006) on two groups of pre-service teachers in the technology-supported PBL in Educational Psychology course. The research was carried out in three semesters and there were consistently positive effects favouring the students in the PBL class on targeted outcomes. Capon and Kuhn (2004) conducted a research on MBA students which randomly assigned to some conditions such as PBL-first, lecture-second or lecture-first, PBL-second for two different topics in Management. The results of this study showed that there was no significant difference on measures of declarative knowledge between above condition, however students in PBL group constructed more integrative explanatory essays for the concepts that they had learned.

PBL approach has also been applied successfully at secondary education. The results of a study carried out by Mergendoller, Maxwell, and Bellisimo (2006) on high school economics students found that students in the PBL course gained more knowledge compared to students in traditional course. PBL approach implemented in a large-scale implementation study comparing students using the Jasper PBL instruction with matched comparison students across 16 school districts in 11 states by Adventures of Jasper Woodbury in middle school mathematics (Cognitive and Technology Group at Vanderbilt [CTGV], 1993). The result of this study indicated that PBL had positive outcomes on standardized tests; however, on researcher-developed measures, the results showed there is no differences between PBL and traditional mathematics instruction on single-step word problems but significant positive effects on solving multistep word problems and on other aspects of problem solving such as planning and problem comprehension for the PBL group. This is important to note that the goals of PBL go beyond traditional measures of knowledge and knowledge application and there is evidence that showed PBL supports the development of reasoning skills (Hmelo et al., 1998), problem solving skills (Gallagher, Stepien, & Rosenthal, 1992) and self-directed learning skills (Evensen & Hmelo, 2000). Schwartz and Matrin (2004) found that students who initially learned through exploratory problem solving in employing statistical principles learned more from a subsequent lecture than students who had initially learned from a worked example that the instructor explained in class. Consequently, PBL approaches are effective at preparing students in their future learning.

To further add to literature of impact of PBL on students learning, many investigations into PBL were undertaken. In its application to instructional designs, the cognitive load theory says that many conventional instructional formats are less than effective because little consideration is given to the concept of cognitive load. As such, many of this method involved extraneous activities that are unrelated to mathematics performance. Evidence of positive impact of guidance during instruction was emphasized on students' learning process. Mathematics students should engage in more real-world problem solving, where situations are complex or ill structured. However, research in problem solving in mathematics is not recent but some past studies focused on a myriad aspect such as heuristics, instructional method, mental schemes and factors affecting word problem solving. Educational boards and councils are advocating instruction where students are actively constructing their ideas and collaboratively engaging in tasks that emphasize the connection of knowledge to the contexts of its application to reform the mathematics education (American Association for the Advancement of Science [AAAS], 1989; National Council of Teachers of Mathematics [NCTM], 1989). Reform documents (National Council of Teachers of Mathematics [NCTM], 2000) emphasized the importance of understanding not only content but ways in which students engage them. There are numerous methods or techniques to improve mathematics learning process. Some of the pedagogical approaches for an effective mathematic teaching and learning are research-based teaching method which is problem-based learning (PBL) and project-based-learning.

Problem-based learning is one of the instructional strategies that are often used to help learners' enhance interactions and higher thinking, by using ill-structured problems that are highly relevant to a subject area, and employ a student-centre approach. Typically, the problem is described as an ill-structured (or messy) problem, since it is open-ended and there is not solely one solution to the problem (Torp & Sage, 1998). In this approach, learners are encouraged to engage with problems and to seek the knowledge needed to develop a possible solution for the main problem of scenario. Consequently, PBL is an instructional strategy that may effectively increase learners' motivation and retention of information as they actively use critical thinking skills to solve problems (Schwartz, Mennin, & Webb, 2001). Problem-based learning is not a new concept of learning, but more and more learning institutes' showed interest and adopted this approach which stemmed primarily from Barrow's problem-based learning model.

Barrows developed the PBL approach for the medical school program at McMaster University in the early 1970s. He created scenarios where students could apply skills to a real-life problem-solving situation. Furthermore, problem-based learning gives learners the possibility of becoming active participants in the learning process and they could obtain meaningful connections between the content and the problem which is hidden in scenario. Moreover, problem-based learning may also offer opportunities for learners to engage in exploration of solving problems and developing critical thinking (Smith & Stock, 2003; Applebee, 2003). Information-processing theory, cooperative learning, constructivist learning, and contextual learning theory provide theoretical framework for PBL.

The issue of learning problems in mathematics, mathematical thinking and problem solving has not been resolved till today. However, despite disagreements among educators and mathematicians on effective learning approach, it is clear that there is consensus with regards to poor mathematics performance among learners. Thus this investigation on PBL may provide some evidence of enhancement of mathematics learning.

2. Method

The quasi-experimental *post-test control group design* was employed. This study examined performance of postgraduate students who were taking Educational Statistic course. Six PBL Modules which consisted of scenarios and guided questions were developed by the authors and were used over a period of 10 weeks lessons. Two statistic tests were conducted to assess the students' performance in Educational Statistic through PBL and conventional learning mode. Two sets of test were conducted: Test I may be regarded as post-test 1 whilst Test II as post-test 2. General linear model (GLM) multivariate procedure was employed to test the effects of PBL and conventional teaching approaches. In this study, problem scenario, guided questions and assessment questions posed as platform towards collaborative work for students in each group. Their final goal is to produce a presentation of problem solution for the assessment questions.

During the intervention, students form group of three and undergo cooperative, collaborative activities using the PBL Guided Questions Module. Each module covers one topic in Educational Statistics for example Basics of Inferential Statistical Analysis, Test of Differences between Sample Mean and Population Mean, Test of Differences between Two Means, etc. Each package starts with learning outcomes to be achieved and followed by problem scenario. In processing and understanding the problem scenario, students were given guided questions and to be answered in the given order. Students were also given notes highlighting and focusing on the important concepts and the learning outcomes to be achieved. Students were also encouraged to source information on the website and any textbooks suggested for the course. Students were encouraged to answer the questions by using multiple resources prepared and suggested by the instructor. Students were asked to complete the first problem scenario with guided questions before proceeding to the second problem scenario. During this session the instructor act as facilitator providing guidance and monitoring the discussion based on the questions provided in the PBL Guided Questions Module. In addition, they were given the assessment questions and were told to work collaboratively on their own chosen time. The next session then starts with each group representative presenting the solution of the assessment questions. Students understanding and misunderstandings were clarified and concluded during this session.

3. Results

The findings of this study were mainly based on the experimental data gathered from the respondents. Two performance tests were conducted and the following were the test scores for each group, the PBL and the conventional group. Generally the PBL group scored higher than the conventional learning group, except for the objective part of Test 1. Inspection of the following tables indicated the higher performance of the PBL group.

Table 1. Descriptive statistics of mean students' performance from the PBL and conventional group

Test	Group	*M*	*SD*	*n*
Test1- Objective	PBL	74.6237	9.68685	31
	CI	75.0505	12.25088	33
Test1- Subjective	PBL	73.7097	14.81709	31
	CI	62.9545	19.94822	33
Test2 - Objective	PBL	66.7097	10.94895	31
	CI	66.9360	13.33053	33
Test2 - Subjective	PBL	81.7204	13.71539	31
	CI	76.3232	19.80469	33

Table 2. Independent samples t-test

		Levene's Test for Equality of Variances		t-test for Equality of Means						
									95% Confidence Interval of the Difference	
		F	Sig.	*t*	*df*	Sig. (Two-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
Test1Obj	Equal variances assumed	1.450	.233	-.154	62	.878	-.42685	2.77249	-5.96897	5.11527
	Equal variances not assumed			-.155	60.286	.877	-.42685	2.75226	-5.93166	5.07796
Test1Sub	Equal variances assumed	5.405	.023	2.436	62	.018	10.75513	4.41532	1.92904	19.58123
	Equal variances not assumed			2.458	58.940	.017	10.75513	4.37500	2.00058	19.50968
Test2Obj	Equal variances assumed	2.561	.115	-.074	62	.941	-.22635	3.06054	-6.34428	5.89158
	Equal variances not assumed			-.074	60.940	.941	-.22635	3.04171	-6.30875	5.85605
Test2Sub	Equal variances assumed	4.930	.030	1.260	62	.213	5.39720	4.28477	-3.16793	13.96233
	Equal variances not assumed			1.274	57.131	.208	5.39720	4.23719	-3.08720	13.88159

The comparison for mean performance between the PBL group and the CI group are shown descriptively in Table 1. It was found that the PBL group performed better compared to the PBL group in solving subjective questions for both tests. Comparison of the means performance for the PBL group and the CT group showed there was a significance difference between the PBL group (M = 73.71) and the CT group (M = 62.95) with $t(62) = 2.44$, $p < .05$) based on test 1 results. The magnitude of the differences in the means was moderate with an eta squared = 0.13.

A multivariate analysis of variance was conducted to assess if there were differences between the two teaching approaches on a linear combination of four types of tests. The assumption of independence of observations and homogeneity of variance/covariance were checked and met. Bivariate scatter-plots were used to check for multivariate normality. A significant difference was found, Wilks'Λ = .858, $F(4, 59) = 2.450$, $p = .056$, multivariate η= .142 (refer to Table 3).

In examining the coefficients for the linear combinations of distinguished performance categories, it was concluded that performance in subjective questions for both tests 1 and 2 contributed most to distinguishing the groups. In particular, both subjective questions contributed significantly toward discriminating the groups. Objective test performance did not contribute significantly to discriminate between the two teaching approaches. Follow-up analyses indicated that test 2 performance for the subjective part were significantly different for students in the different learning mode, F (1, 62) = 5.933, p = .018. Test 2 was conducted after the 10th week of teaching and learning, thus indicating sufficient improvement of the students.

Collaborative learning refers environments in which learners engage in a common task in which each individual depends on and is accountable to each other. Groups of students work together in search for understanding, meaning or solutions or in creating their learning. The approach is closely related to cooperative learning. Collaborative learning activities can include collaborative writing, group projects, and other activities. Collaborative learning has been suggested as an excellent method of helping students to learning. The experience gives an opportunity to students in order to work together, develop the sense of teamwork and pride (Pewewardy, 2002; Reyes, 1991; Swisher, 1990).

Table 3. Multivariate tests of students' performance from the PBL and conventional group

Multivariate Tests

Effect		Value	F	Hypothesis df	Error df	Sig.	Partial Eta Squared	Noncent. Parameter	Observed Power[b]
Intercept	Pillai's Trace	.983	853.078[a]	4.000	59.000	.000	.983	3412.310	1.000
	Wilks' Lambda	.017	853.078[a]	4.000	59.000	.000	.983	3412.310	1.000
	Hotelling's Trace	57.836	853.078[a]	4.000	59.000	.000	.983	3412.310	1.000
	Roy's Largest Root	57.836	853.078[a]	4.000	59.000	.000	.983	3412.310	1.000
Groups	Pillai's Trace	.142	2.450[a]	4.000	59.000	.056	.142	9.799	.666
	Wilks' Lambda	.858	2.450[a]	4.000	59.000	.056	.142	9.799	.666
	Hotelling's Trace	.166	2.450[a]	4.000	59.000	.056	.142	9.799	.666
	Roy's Largest Root	.166	2.450[a]	4.000	59.000	.056	.142	9.799	.666

4. Conclusion

University students often learn mathematics through traditional approaches. This study aimed at examining the effectiveness of new teaching approaches on the performance of the students. On the whole, the study showed that PBL, as a new approach, has significant influence on the students' performance. The question remained was whether these approaches could increase the students' cooperative and collaborative learning abilities? Central to the effectiveness of PBL is the ability of students to work together in order to solve problems. Hence, PBL lessons can be designed to facilitate collaborative learning of mathematics by students. This was possible because the characteristics of PBL such as learning collaboratively in small groups, activating prior knowledge through group discussion, having a teacher to facilitate learning, and having resources at hand to help them solve the given problem were in line with students' cognitive architecture. Findings of this comparative study are consistent with findings reported earlier which focued on repeated measures analysis of statistics performance of students undergoing the PBL mode of learning (Ahmad Tarmizi & Bayat, 2010). Whilst much evidence was obtained on the efficacy of PBL in learning statistics, more extensive research needs to be conducted.

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